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Award Number: W81XWH-06-1-0161

TITLE: Development of a Portable Simulator for Training Robot Assisted Surgery

PRINCIPAL INVESTIGATOR: Jan Sigurd Rotnes, M.D., Ph.D.

CONTRACTING ORGANIZATION: SimSurgery AS
OSLO 0250

REPORT DATE: December 2006

TYPE OF REPORT: Final Proceeding

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
01/12/06

2. REPORT TYPE
Final Proceeding

3. DATES COVERED *(From - To)*
10 Nov 05 – 9 Nov 06

4. TITLE AND SUBTITLE
Development of a Portable Simulator for Training Robot Assisted Surgery

5a. CONTRACT NUMBER

5b. GRANT NUMBER
W81XWH-06-1-0161

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Jan Sigurd Rotnes, M.D., Ph.D.

E-Mail: jsr@simsurgery.no

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

SimSurgery AS
OSLO 0250

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The possibility of using virtual reality sumulators in surgical training was proposed more than a decade ago. This form of training holds the potential of reducing the need for mechanical models and animals in surgical training without compromising surgical outcome in the operating room (OR). Mechanical trainers are being used to train and evaluate laparoscopic surgical skills, but compared to virtual reality simulators the assembly of mechanical trainers is time consuming. SimSurgery's vision is to increase clinical performance and to reduce healthcare cost by offering solutions for better training and computer assisted tools in surgery.

15. SUBJECT TERMS
Telemedicine, telecommunications, interoperability, health care.

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			USAMRMC
U	U	U	UU	11	**19b. TELEPHONE NUMBER** *(include area code)*

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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INTRODUCTION

With the introduction of computer enhanced telemanipulators (surgical robots), complex surgical procedures such as thoracoscopic coronary artery anastomosis or laparoscopic radical prostatectomies have become feasible (1,2). Robot assisted endoscopic procedures are associated with a definite learning curve (3), where surgical technical skills are expressed as a function of time used for training. The standard way of gaining the necessary surgical technical skills has until recently been by training in a dry lab followed by training on animal models (2) or, more commonly, by learning technical skills in the operating room using the 100 years old Halstedian principle "see one, do one, teach one" (4).

The possibility of using virtual reality simulators in surgical training was proposed more than a decade ago (5). This form of training holds the potential of reducing the need for mechanical models and animals in surgical training without compromising surgical outcome in the operating room (OR). Mechanical trainers are being used to train and evaluate laparoscopic surgical skills (6), but compared to virtual reality simulators the assembly of mechanical trainers is time consuming. After each session mechanical trainers have to be reassembled and prepared again for the next student, and they do not allow automated measurements of surgical performance. Seymour, et al. have published a study which claims to show that virtual reality training improves operating room performance (7).

SimSurgery (8) has developed technology for virtual reality simulation with special focus on surgical suturing and soft tissue deformation such as tissue dissection. SimSurgery´s vision is to increase clinical performance and to reduce healthcare costs by offering solutions for better training and computer assisted tools in surgery. SimSurgery was established in September 1999 to develop and sell medical simulation software for virtual training and planning. The company's unique software for simulating minimally invasive surgery (MIS) has been developed by a closely knit team of highly competent specialists. The first product for training laparoscopic suturing sold in the EU and US in 2003.

Master slave robots used in minimally invasive surgery operate by transforming the surgeon's hand movement into fine precise instrument maneuvers. The most dominating vendor of surgical robot systems is Intuitive Surgical (Sunnyvale, CA) (9) with its master slave robot da Vinci. The 3 or 4 arms moving the surgical instruments (slave) are controlled by a surgeon console (master) that convert the movement of the surgeons hands into precise instrument trajectories in a very elegant and intuitive way. The mechanical system comprising the master console is rather complex (expensive and large size) to meet demands for clinical use.

However, it is possible to develop a device that utilizes a modern motion tracking system similar to the surgeon robot console. A robot console developed only for training is not limited by the clinical requirements experienced in a real robot system. Such a motion tracking based system has potential for being less complex and less expensive than the clinical console.

BODY

4.1 Significance and/or Uniqueness of the Effort

To develop a portable surgical robot simulator, solutions for five fundamental problems outlined below must be found. SimSurgery has been addressing these problems with a strong focus and significant commitment for five years (company established in 1999). During these years, basic research in mathematics, physics and computer graphics from Europe and the US has been utilized. SimSurgery has patents pending that address solutions for surgical interfacing, suturing and soft tissue modeling. SimSurgery is part of a corporate structure with expertise in 3D animation and graphical entertainment solutions. SimSurgery has access to cutting-edge technology and competence within the field of computer graphics and computer networks for distributed solutions. The SimSurgery roots are partly from the Interventional Centre at the Norwegian National hospital. This research centre for telemedicine and surgical robotics was one of the first European sites performing robot assisted operations. The head of the Interventional Centre, Erik Fosse, is an experienced war surgeon who will participate in the project.

The 5 fundamental problems:

1) <u>Development of a surgical interface that transforms the surgeon's instrument maneuvers into similar movements of the virtual reality instruments.</u>

SimSurgery has developed a new type of instrument interface, the SimPack™, focusing on measuring the movement of instruments, whether they are inside or outside the simulated patient's body. This approach allows random placement of ports relevant for different types of procedures and patients (e.g. operation on children and obese patients). The instrument holder is specially designed for easy change of different surgical instrument grips such as needle drivers, graspers and video scopes. Just as it is flexible in terms of different grips; it can be used in robot assisted laparoscopy, robot assisted open surgery and non-robotic open surgical procedures. SimPack™ is constructed for easy portability and can be attached to ordinary laptop or desktop computers. SimPack™ will be produced as a commercial product for laparoscopic training in Q4-2004, but the potential use for robotic and open surgery needs further development.

2) <u>Solutions for modeling soft tissue with proper geometric representation that is undergoing transformation due to instrument interaction, tissue cutting and removal.</u>

In modelling objects, SimSurgery applies a core technology called Sim3DM®. In simple terms, Sim3DM® enables virtual objects to behave like real ones in the medical field. Software packages such as 3D Studio Max can help a user produce 3D animation. Although the user probably will not notice, these standard software packages generally build a 3D object from a large number of basic shapes (often polygon based). When the 3D objects are made to change shape, rotate or otherwise move around, the computer (or graphic card) will recalculate the position of all the small geometries that make up the object. For a number of reasons, this standard modelling approach cannot easily be applied in simulated surgery.

- In standard 3D modelling, rendering is often slow because the movement of an object requires heavy computation of each building block – simulation will not be in real time.
- Standard 3D modelling is slow at detecting whether one object touches another object; the process involves calculating the position of every node or triangle in an object and then checking if another object occupies the same position.
- Standard 3D modelling cannot easily incorporate deformable objects. (Your Nintendo racing game would typically show the car either unscratched or wrecked.)
- Standard 3D modelling is not well adapted at giving measured responses when objects interact. In a 3D video game, when one object hits another, you would typically experience just a few possible outcomes: the body either stands or falls.

Sim3DM® has a different approach compared to standard computer assisted animation. This makes it ideal for highly demanding medical simulation applications. Like a sculptor or sculptress working in a stone quarry, Sim3DM® first cuts the basic building block(s). The block is then refined to a rough, square figure defined by a mesh. Then, the surfaces are "polished" into an even shape by a set of equations that define the curves of the object. This approach is efficient inasmuch as it builds a 3D model with less data and allows for efficient rendering, collision checks etc. Each part of the Sim3DM® object can be assigned properties such as elasticity and connectivity (how one part of the object relates to other parts). When exposed to a force (pressure, dragging, etc.) the software can easily calculate how the object responds.

3) <u>Solutions for modeling a surgical suture, stitching and interaction between several soft and moving objects such as the tissue, instruments and the suture</u>

We model the suture as a sequence of segments where the length of the total thread is invariant. Some of the segments are embedded in tissue and the rest are located in free air. One segment ends and another starts where the thread leaves the air and enters the tissue or vice versa. These stitch points together with the end points of the whole thread make the vertices of a ``stitch polygon". When the length of the stitch polygon is shorter than the prescribed fixed length of the thread, one or more of the free segments have slack, otherwise they are straight lines. The embedded segments are always represented as straight lines. The distribution of slack between the segments is done in an ad hoc manner. When the stitch polygon is longer than the thread, the stitch polygon must be replaced by a shorter one, meaning the tissue is pulled together. A blend polygon of correct length can be found by solving some nonlinear equation system.

A free segment of prescribed length, only constrained at its end points, can be modelled as an elastic curve with flexural stiffness and mass density. Animation of the segment is then modelled as a sequence of stationary states with minimum potential energy due to bending and gravity. A stationary state, and hence the curve shape, is determined by the prescribed length and spatial end conditions for the segment. The bending energy of an arc length parameterized curve is proportional to the integral of its squared second derivative.

To avoid the free segment penetrating tissue; tools and the model for free segments must be modified. Dynamic models make use of hit/collision detection and repulsive forces between the thread and objects not to be penetrated.

4) Visual realism in terms of graphics.

SimSurgery exploits all new technology offered by the graphic industry such as graphic cards and modeling software such as Maya. SimSurgery has unique expertise in providing graphical realism. SimSurgery also has a close collaboration with animation groups producing advance 3D animated motion pictures and clinical groups in Norway. The clinical partners provide important feedback in the modeling of surgical scenes and other material such as videos and access to PACS archives for 3D image data.

5) Realism in terms of physical models controlling the soft tissue models (dynamic behavior of the geometry).

As for the physical model, the finite element model is a discrete formulation of a continuum. Another method is the spring-mass model that represents a division of the physical object into particles (distributed masses) with springs connecting the particles. The spring-mass model yields a simpler and more flexible model, but does not give as realistic responses as finite element models. SimSurgery has used combinations of different models. It should be noted that the Sim3DM data structure allows easy integration of new physical models, optimized according to surgical requirements and computer speed.

4.2 Hypothesis

It is possible to develop a portable device that resembles the surgeon console in a surgical robot system, as well as, surgical simulator software that replaces the need for biological tissue (animals or patients) and/or equipment.

4.3 Technical Objective

The technical objective of this project was to develop a portable device that resembles the surgeon console in a surgical robot system, as well as, surgical simulator software that replaces the need for biological tissue (animals or patients) and/or equipment. The first phase focused on the development of a small demonstration system for training basic skills such as instrument manipulation and suturing. The next phase will be to develop a specific robot assisted procedure utilizing the portable robot master.

4.4 Military Significance:

The proposed project has relevance for the US military in 4 ways:

1) Use in surgical educational programs within the US military for learning robot assisted surgery or open surgical procedures.

The portable robot simulator will be designed with an educational model that directly relates to general surgery standards. This will include an embedded performance measurement of terminal learning objectives for robotic surgery or open surgery. The educational model centers on the development of terminal learning objectives for surgery procedures focusing on cognitive, psychomotor, and judgment skills. The learning objectives will reside and be embedded as part

of the portable platform. For example, based on the terminal learning objectives, it is likely that much of the training objectives reside in the graphics and visualization component so that the robotic approach is transferable to general surgical training. This approach will facilitate development of a performance model that matches the appropriate technical features to specific learning objectives. In addition, within the core software architecture, specific patients will be created for particular surgical scenarios. These will include robot assisted laparoscopy, robot assisted open surgery and open surgery in general with task components such as debreedement, arterial bleed, dissection, spleenectomy, appendectomy, and colon resection. Embedded student performance metrics will be included.

2) Use for training paramedics to deal with trauma and open surgical procedures by providing a 6 degree of freedom interactive environment.

The two handed 6 degree of freedom SimPack™ (with additional grip and other instrument controls) enables interactive environments for hand-eye coordination exercises. In addition to using the platform in learning basic surgical tasks relevant for trauma scenarios, the platform provide a portal to train on communication procedures, triage and decision making in combat situations. This is accomplished by connecting several SimPorts™ together in a network interfaced to the same virtual world. SimSurgery's special access to 3D animation technology and surgical competence with war surgery experience has been an important part of the company's uniqueness since it was established.

3) With surgical robots at remote sites, the project offer solutions for learning to use the surgical robot and for telementoring surgeons on the remote site using the robot.

One of the potential benefits of using surgical robots for the U.S. military is the possibility of using the robots on remote sites with limited access to surgical specialists. The robot can be used as an enabling tool to help the surgeon carry out complex operations, perhaps with little on site assistance. In addition to being an advanced tool, the robot is also a platform that enables remote control (telesurgery) or remote guidance (telementoring). The portable robot simulator is a cost effective device to learn and it is a practical and cost effective device for telementoring. A large group of experts having access to the platform, offers the possibility of finding the right expert to assist in emergency situations at remote sites.

4) With future surgical robots that are completely controlled by a remote center for use in combat fields, the project offers a solution to learn the use of such robots without the cost of training on a real system.

There are many ongoing projects trying to develop robot systems that can carry out emergency tasks in combat fields or other dangerous environments. The use of such robot systems requires remote control of the robot from dedicated personnel with the right skills and experience. A portable simulator would be a cost efficient device in training and guidance without implementing such robot systems.

4.5 Methods

The standard method, and so far the only way to train robot assisted surgery, is to practice with a complete robotic setup including OR facilities. Such assembly of mandatory equipment makes surgical robot training very expensive, thus render a significant limitation in providing robot assisted procedures to suitable patients. By exploiting surgical simulator technology, it is possible to simulate with a PC anatomical organs (the patient), the OR and much of the robotic equipment. Since the master slave robots used in minimally invasive surgery operate by transforming movements of the surgeons hand into fine precise instrument maneuvers, it is possible to develop a device that utilizes modern motion tracking system in a way similar to the surgeon robot console. A robot console developed only for training is not limited by the clinical requirements encompassed in a real robot system.

SimSurgery platform (SEP) that has been prepaed and tested with 2 surgical robot systems (da Vinci and Zeus from Intuitive Surgical, http://www.intusurg.com). SEP is a general platform for computer based surgical training and education. It is a complete learning system including both hardware and software components that emulate a real laparoscopic situation. SEP is unique in design with regard to how the surgeon interacts with the simulator (SimPack™) and the variations of training exercises. The surgical interface SimPack™ offers the possibilities to resemble different body surfaces with different port placements and enables procedure specific anatomy exploration. The simulator software that uses a standard PC offers a large range of skill training. The simulator displays both abstract and procedure realistic scenes. Many basic skills can be learned in an abstract environment and more advanced skills can be learned in procedure realistic environments. Skill assessment is by validated metrics that reflect the user's competence level. The administration unit in SEP is easily combined with all kinds of additional educational material by embedding tools to access multimedia inside the software. SEP includes modular software for easy update of new training modules. The system has individual applications for administration, training in roaming mode (free selection of exercises), and training in session mode (predefined curriculum). In the session mode, it is possible to require that the user exceed a certain performance level, before he/she can continue to the next set of training exercises.

KEY RESEARCH ACCOMPLISHENTS

- First version (v1) of the portable robot master console for simulation – called SimPack Robot – has been developed and functionality tests have been carried out. Successful testing has initiated final design for commercial product.
- 21 of 25 laparoscopic simulator exercises have been converted to robot assisted exercises.
- SimSurgery personnel have evaluated the 21 working exercises in relation to robotics versus traditional laparoscopy. The evaluation has concluded that the simulator software must manage and record instrument collision. Instrument collision handling will be included in the commercial launch of the software.

REPORTABLE OUTCOMES

Publications:

- Seymour NE, Røtnes JS: Challenges to the development of complex virtual reality surgical simulations. Surgical Endoscopy 2006 (in press, November 2006)

Presentation of the robot prototype simulator at the following exhibits:

- SimSurgery demonstrated SEP-Robot in the TATRC exhibit at the MMVR conference (Medicine Meets Virtual Reality) in Los Angeles, USA, January 2006.

- SEP-SurgicalSim Education Platform was used during training courses and exhibited at SAGES 2006 Annual Meeting in Dallas, Texas, USA, April 2006.

- SEP-SurgicalSim Education Platform was used during training courses and exhibited at 10th World Congress of Endoscopic Surgery and 14th International Congress of the European Association for Endoscopic Surgery (EAES), Berlin, Germany, September 2006.

A commercial robot simulator to be launched at the end of 2006.

- News and brochures - www.simsurgery.com

CONCLUSION

The proposed project aimed to develop a portable device that resembles the surgeon console in a surgical robot system, as well as, surgical simulator software that replaces the need for biological tissue (animals or patients) and OR equipment. The first phase focused on the development of a small demonstration system for training basic skill such as instrument manipulation, tissue dissection and suturing. The next phase will be to develop a specific robot assisted procedure utilizing the portable robot master. This will address basic surgical training objectives also transferable to open surgical procedures.

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